X-ray Observations of Recurrence of Eruptive Flares and Active Regions

David Batchelor

Science Communications Technology Branch

Mail Code 933

NASA Goddard Space Flight Center

Greenbelt, MD 20771 USA

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Abstract. In a study of soft X-ray coronal images obtained with the *Yohkoh* spacecraft, two eruptive flares with remarkably similar X-ray structures were noted — most remarkably because the flares occurred at the same solar location (approximately 10 degrees north latitude on the east limb) yet separated in time by three solar rotations. Between the times of the eruptions, the active region responsible for the first flare disappeared from *Yohkoh* images. An extremely similar X-ray active region replaced it by the third solar rotation. The recurring X-ray active region appearance and recurring flare activity after 86 days suggest that persistent subsurface flux emergence patterns might be responsible, and support previous arguments that "active longitudes" exist.

Yohkoh soft X-ray images of the full Sun have been available from the *Yohkoh* science team for some years, courtesy of the Solar Data Analysis Center at NASA's Goddard Space Flight Center (see archive images available from the synoptic solar database on the SOHO World Wide Web Page, at URL http://sohowww.nascom.nasa.gov/data/synoptic/).

In surveying these images, it was noticed that an eruptive flare was visible in the 1995 May 5 image (Fig. 1, upper right) which resembled an earlier flare in the 1995 Feb. 8 image (Fig. 1, upper left). The form of the "helmet streamer" structure in the May X-ray image appeared to reproduce the form of the Feb. structure, and at approximately the same solar latitude. This motivated study of the regions when they rotated to central meridian (CM) passage (Fig. 1, lower left and lower right). North is up, and it can be seen that the northern active regions (responsible for the flares) in the CM images are similar. Note that the active regions, or soft X-ray "sigmoid brightenings," also exhibit the same "S" shape distortion sense, due to the twist in magnetic field lines (Rust and Kumar, 1994, 1996).

For comparison, in Fig. 2 the CM passages of the same solar surface location on the intervening two Carrington rotations are shown. It is seen that the Feb. active region had faded in the March CM passage, and was completely dispersed by the April CM passage. To confirm the disappearance of the active region by Apr. 10, the Kitt Peak National Observatory synoptic magnetograms were also inspected. The magnetic regions that had been visible at CM passage on Feb. 15 were no longer visible in magnetograms on Apr. 10. (These magnetograms may also be obtained at the SOHO synoptic data WWW page.)

When a new active region appeared in the May rotation, Fig. 1 shows that it was very similar in size and helicity to the Feb. appearance of an active region at that location. This provides strong evidence that subsurface flux emergence structures sometimes persist for many solar rotations and produce repeated eruptions of similar magnetic active regions.

Reference to Solar Geophysical Data reports indicates that the Feb. active region was number 7838 (Carrington rotation 1892) observed at 8° N, and the corresponding May active region was number 7870 (Carrington rotation 1895) at 10° N (not significantly different, given the uncertainties in location). Using the mean of these latitudes, the synodic rotation period of the solar surface at this latitude is approximately $(26.75 + 5.7 \sin^2 (9°))^d = 26.89^d$ (Allen 1976). However, under the assumption that a persistent subsurface structure produced both the Feb. and May surface active regions, measurement and analysis of the *Yohkoh* images at CM passage imply a synodic rotation period of 29.3^d per rotation, 93% as rapid as the surface rate.

This phenomenon may be explained by the model of Rust and Kumar (1994), in which subsurface helicity accumulations cause recurrent ejections of magnetic flux from the solar interior, producing active regions. Bieber and Rust (1995) discuss how this process is manifested in coronal mass ejections, where the helicity is measurable in space.

SOHO Michelson Doppler Interferometer measurements have been used to deduce the rotation rate of the solar interior versus latitude and depth (Kosovichev *et al.* 1997), and the results suggest that near the convection zone boundary, rotation is slower than the surface and approximates rigid-body rotation. Rotation speeds as much as 93% slower than the surface are consistent with the *SOHO* MDI results (see the figure on p. 59 of Kosovichev *et al.,* or the WWW version at URL http://soi.stanford.edu/results/srotation.html). The rotation rate of the structure discussed in this paper is consistent with an origin at depths where such slower rotation occurs, such as $r/R = 0.6$ in the figure from Kosovichev *et al.* There is strong theoretical evidence that at such depths, the Sun has a strong magnetic field, as shown recently by Gough & McIntyre (1998), so upwellings from such a depth below the "tachycline" would be expected to contain strong magnetic fields.

These observations also support the suggestions of "active longitudes" which have been detected in power-spectrum analyses of solar flare occurrences (Bai, 1988; Kiplinger *et al.*, 1984; McIntosh, 1981; Svestka, 1976). On this timescale of three rotations (shorter than the runs of data used in the references), the Sun is clearly able to re-use quite durable internal magnetic structures which apparently make near-repetition of coronal eruptive flares possible. The approach of quiet Sun phase probably enabled this recurrence to be noticed, due to the relative isolation of these active regions.

Acknowledgements

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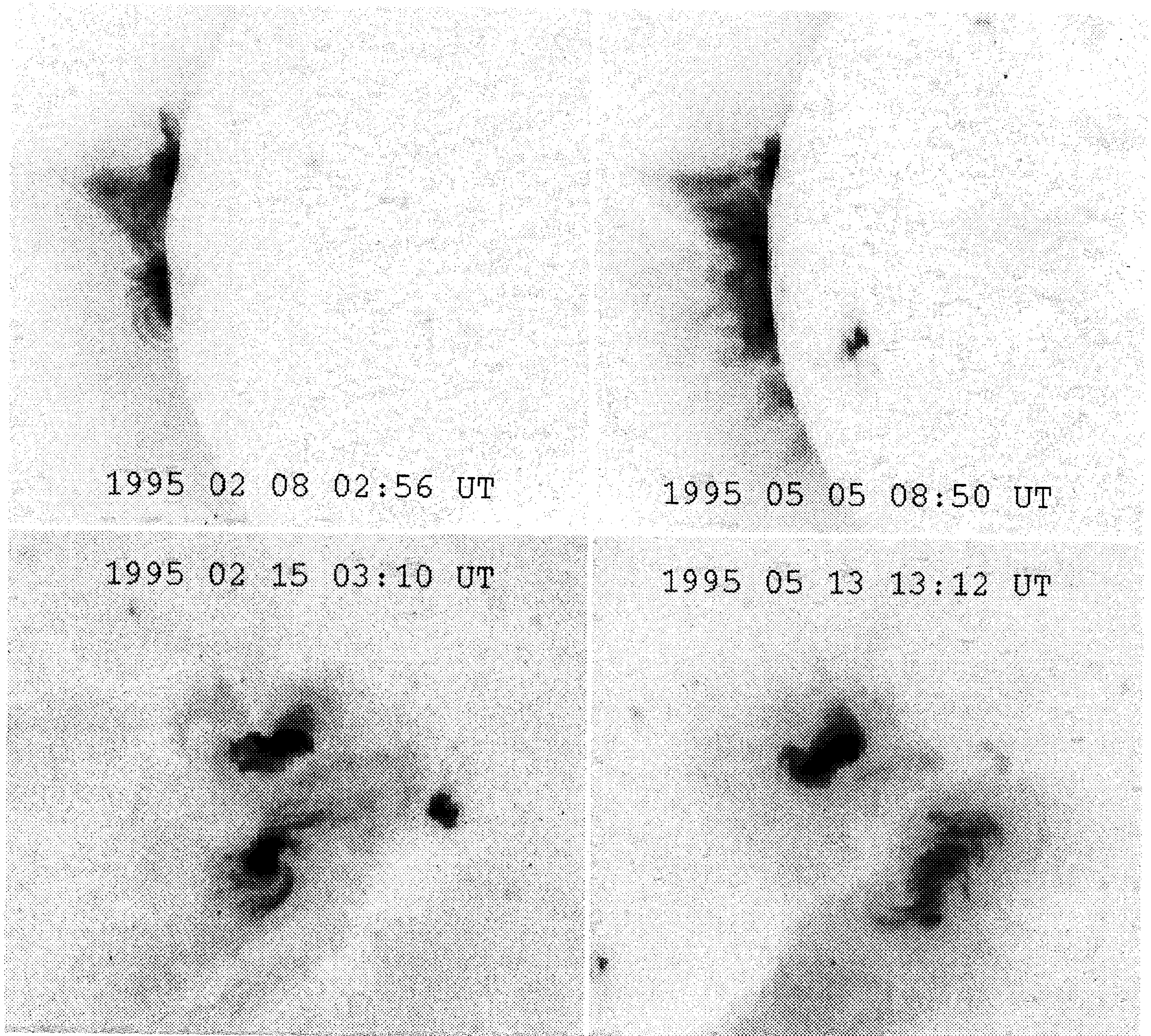
FIGURE CAPTIONS

Fig. 1. The first helmet-streamer eruptive flare and the similar, recurrent flare (upper two pictures) at the east limb (North is up). The bottom two pictures each show the central meridian passage one week after the picture above it. In the upper pictures, note the similarities of the helmet streamers, despite the intervening three solar rotations.

Fig. 2. The March and April central meridian passages of the active regions pictured in the bottom pictures in Fig. 1., displayed using the same gray-scale levels. It can be seen that after one rotation, the active region responsible for the first helmet-streamer flare had faded, and after a second rotation, it had dispersed.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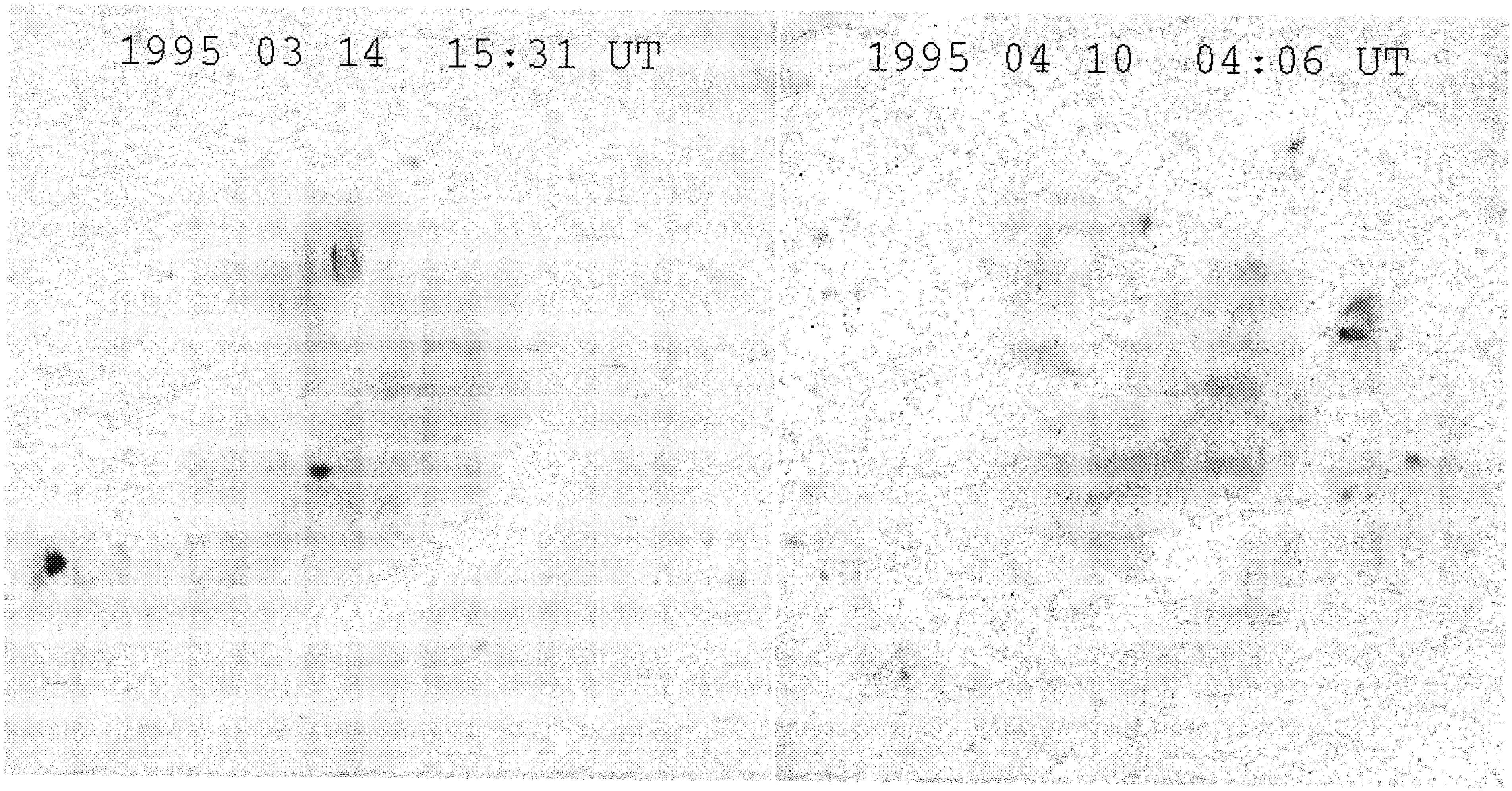
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